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An analysis of the costs and benefits in improving F402-RR-406A high pressure turbine, second stage blades under the Aircraft Engine Component Improvement Program (CIP)

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An Analysis of the Costs and Benefits in Improving F402-RR-406A High Pressure Turbine, Second Stage Blades Under the Aircraft Engine Component Improvement Program (CIP)

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This thesis is part of a continuing project at the Naval Postgraduate School attempting to validate the cost effectiveness of the Aircraft Engine Component Improvement Program. It focuses on the costs and benefits derived from Power Plant Change 159 which improved High Pressure Turbine, Second Stage blades on the Harrier (AV-8B) aircraft's Rolls-Royce Pegasus (F402-RR-F406A) engine. Because sufficient failure rate data for the improved blades was not available, the analysis considers a range of costs/benefits based on two different projected blade reliabilities. The improvement to the High Pressure Turbine, Second Stage blades was found to be cost-effective from both a financial break-even point, in that the cost to produce the improvement will be recovered by the end of 1996 for the full range of projected blade reliabilities and from a Net Present Value analysis which shows that this improvement will save the Department of the Navy between $17,192,827 and $38,639,494 (in 1992 dollars) over the projected life cycle of the engine.

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This thesis is part of a continuing project at the Naval Postgraduate School attempting to validate the cost effectiveness of the Aircraft Engine Component Improvement Program. It focuses on the costs and benefits derived from Power Plant Change 159 which improved High Pressure Turbine, Second Stage blades on the Harrier (AV-8B) aircraft's Rolls-Royce Pegasus (F402-RR-F406A) engine. Because sufficient failure rate data for the improved blades was not available, the analysis considers a range of costs/benefits based on two different projected blade reliabilities. The improvement to the High Pressure Turbine, Second Stage blades was found to be cost-effective from both a financial break-even point, in that the cost to produce the improvement will be recovered by the end of 1996 for the full range of blade reliabilities and from a Net Present Value analysis which shows that this improvement will save the Department of the Navy between \$17,192,827 and \$38,639,494 (in 1992 dollars) over the projected life cycle of the engine.

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I. INTRODUCTION

A. BACKGROUND

To sustain aircraft readiness in an era in which resources are increasingly being constrained, it is imperative that major claimants, and their related program sponsors, effectively manage their budgets. Budget requests must be formulated and prioritized to accurately reflect the needs of the fleet in performing the missions of Naval aviation. Aircraft engines represent a significant portion of the Naval aviation budget and programs which affect engines must be scrutinized to ensure the prudent use of limited funds.

The Component Improvement Program (CIP), which garners a substantial portion of the aviation budget for engines, was designed to enhance the readiness of engines (and related components) and to reduce life-cycle costs. It has been suggested that CIP saves the government many times the investment costs in the form of reduced life-cycle operational and support costs. [Ref. 1] But, recent cuts in CIP funding may put the Navy's programs in serious jeopardy. In fiscal year 1994 only 273 ($62,800,000) of 416 ($99,864,850) required Navy CIP tasks were funded. For fiscal year 1995 it is projected that CIP will be funded only $55,997,000 from a required $101,500,000. [Ref. 2] If the Component

Improvement Program has a direct, positive impact on fleet readiness, safety, and operating costs, then it would seem prudent to protect CIP from budget reductions. However, validation of CIP costs and benefits has proven to be a difficult process. Continuing research is needed to accurately portray the return on investment of CIP to ensure that the Navy and Marine Corps are getting the "most bang for the buck."

The Component Improvement Program typically calls for significant initial investment with the expectation of reduced life-cycle costs from improving reliability and maintainability and from the correction of service-revealed deficiencies. Specifically, the objectives of CIP are: [Ref. 3]

- To maintain an engine design which allows the maximum aircraft availability at the lowest total cost to the government (primarily production and support costs).
- To correct, as rapidly as possible, any design inadequacy which adversely affects safety-of-flight.
- To correct any design inadequacy which causes unsatisfactory engine operation or adversely affects maintainability and logistic support in service.

The need to justify the high investment costs of CIP has been the motivation for several theses conducted at the Naval Postgraduate School which have attempted to correlate expended CIP funds with tangible benefits. These theses have focused on quantifying the CIP investment costs and the meaningful savings after a modification to an engine component has been made. One of the important objectives of the Naval Postgraduate School's research effort is to show conclusive evidence that the Component Improvement Program is cost-effective. It is the goal of this thesis to further contribute to establishing a linkage between CIP costs and benefits.

B. OBJECTIVES

Desert Storm proved that the AV-8B Harrier is essential to Marine Aviation. As a consequence, this aircraft type must be supported for the long term. This thesis focuses on the CIP effort for the Rolls-Royce Pegasus (F402) engine used on the AV-8B Harrier aircraft. The objectives of this thesis are to:

1. Examine the data bases available for extracting logistic cost/benefit information concerning the F402 engine, and identify problems associated with gathering meaningful information from these data bases.

2. Determine the impact of one significant CIP effort for one component on the F402 engine (hopefully as a bellwether of overall CIP cost-effectiveness for the F402).

3. Determine whether the Component Improvement effort for the selected component was, in fact, cost-effective.

4. Refine the methodology for analyzing the Component Improvement Program for the F402.

C. RELATED RESEARCH QUESTIONS

The primary questions this thesis seeks to answer are:

1. For what reasons was a single, selected Component Improvement Program modification to a significant F402 component performed?

2. What were the total costs to incorporate a change to this selected "high impact" component?

3. Can the changes,if any, to this component be accurately assessed given the modification was performed relatively early in the component's life-cycle and the data needed to precisely determine the impact of the CIP effort is incomplete?

4. What will be the estimated total benefits as a result of the CIP effort to this component?

D. SCOPE AND LIMITATIONS

It was highlighted during Desert Storm that the High Pressure Turbine Section, Second Stage (HPT-2) in the Harrier's Pegasus engine experienced undo failures which threatened safety-of-flight, degraded aircraft availability, adversely affected aircraft maintainability, and increased life-cycle costs. The primary cause of HPT-2 failures was the failure of HPT-2 rotor blades. HPT-2 rotor blades present an ideal component for study as these blade failures caused catastrophic damage. Power Plant Change (PPC) 159 was the CIP resolution to HPT-2 blade problems. Therefore, this thesis will focus on the costs and benefits of PPC 159.

There are limitations to this research. First, this thesis only looks at one improvement for one component for the F402 engine. Second, data sources are many and diverse and changing Work Unit Codes (WUCs) for F402 components make an already difficult process of data collection and analysis even more difficult. Compounding this problem are changes made to the F402 in its development. From 1983 until the present the Pegasus has been redesignated four times.

E. ORGANIZATION OF STUDY

Chapter II provides a literature review of previous research conducted concerning the Component Improvement Program. Chapter III provides the background for analysis and evaluation for determining the impact of Power Plant Change 159. Included in Chapter III will be a technical F402 engine background, the process used to decide which component to analyze, the PPC 159 background and the data collection process. In Chapter IV the author formulates life-cycle cost models for HPT-2 blades with and without the CIP modification incorporation. Chapter V contains break-even and net present value analyses resulting from the application of the models presented in Chapter IV. Finally, in Chapter VI the author provides a summary, conclusions, and recommendations for future study.

II. LITERATURE REVIEW AND PREVIOUS RESEARCH

This Chapter presents a review of the literature and the previous research conducted concerning the Component Improvement Program. The author begins this review with a report performed by the Institute for Defense Analysis which has become the basis for CIP research. The remaining review focuses on the research conducted at the Naval Postgraduate School, begun in 1990, at the request of N-881, the Naval Aviation Maintenance Division of the office of the Assistant Chief of Naval Operations (Air Warfare), and AIR-536, the Propulsion and Power Division of the Naval Air Systems Command.

A. POLICY OPTIONS FOR THE AIRCRAFT TURBINE ENGINE COMPONENT IMPROVEMENT PROGRAM

A paper prepared by the Institute for Defense Analysis (IDA) for the Under Secretary of Defense (Acquisition) discussed the role of, the costs and benefits of, and the policy options concerning the Component Improvement Program. [Ref. 4] The paper provides insight from a macro point of view into the effectiveness of CIP in meeting CIP objectives. The paper's authors describe in detail the functions of CIP and the resources needed to accomplish a CIP task. The authors conclude that the benefits from CIP efforts substantially outweigh CIP costs.

B. EVALUATION OF AIRCRAFT TURBINE ENGINE COMPONENT REDESIGNS

A thesis, written by Sudol and Price, examined some of the problems associated with determining the benefits accrued from CIP. [Ref. 5] The backbone of the thesis was the development of a component selection process for study and a methodology for measuring changes in the component's logistics parameters. The thesis also demonstrated the data collection difficulties encountered in the process of isolating and measuring CIP benefits. The major contribution of the authors to CIP research and this thesis is that they concluded that the effects of CIP are more effectively assessed at the component level rather than at the system (engine) level. They based this conclusion on the theory that the effects of a specific CIP effort could easily be "lost" if the logistics parameter changes (as a result of a single CIP action) were viewed from the engine level because of the complex interactions of engine components.

C. AN ANALYSIS OF THE AIRCRAFT ENGINE COMPONENT IMPROVEMENT PROGRAM (CIP): A LIFE CYCLE COST APPROACH

Borer [Ref. 6] attempted to identify life cycle cost models used by the Navy and other services to determine CIP benefits. Comparing Visibility and Management of Operating and Support Costs (VAMOSC) data for seven aircraft types from 1984 to 1986, he compared Mean Flight Hours Between

Maintenance Actions (MFHBA) and Mean Maintenance Hours per Maintenance Action (MMH/MA) to show support improvements in aircraft reliability and maintainability. Although the author was able to demonstrate general improvements in both MFHBMA and MMH/MA at the organizational and intermediate levels of maintenance for the seven aircraft types, Borer was not able to clearly identify a cause and effect relationship between CIP expenditures and support parameter improvements.

Borer's findings validated the observation of Sudol and Price that a researcher must concentrate on the component level rather than the system level in order to directly correlate CIP investments with improvements. This thesis will follow the premise that CIP research should be conducted at the component level.

D. PRELIMINARY ANALYSIS OF THE J-52 AIRCRAFT ENGINE COMPONENT IMPROVEMENT PROGRAM

Butler's [Ref. 7] objectives were to associate the CIP costs with improvements made pertaining to the J-52 engine and to identify the problems associated with gathering information from various existing data bases when researching the cost-effectiveness of the CIP. He showed that of the ten Engineering Change Proposals (ECPs) he studied only one could be conclusively correlated to an improvement in engine reliability. The author only used cost information from the manufacturer's ECP document.

Butler found it frustrating to extract information from the available data bases available. He examined the Naval Aviation Logistics Data Analysis (NALDA) database, the Maintenance, Material, and Management (3-M) database, and the Aviation Engineering Maintenance System (AEMS) database. The author concluded that while these databases contained a plethora of information, they were too difficult to use. He further concluded that "even if the information was readily available concerning component improvements, the task of determining success or failure would be daunting." Butler believed that the complex interaction between engine components and the impact of various improvements made to many engine components simultaneously made CIP effectiveness assessment perplexing.

E. AN ANALYSIS OF THE CORRELATION BETWEEN THE J-52 COMPONENT IMPROVEMENT PROGRAM AND THE IMPROVED MAINTENANCE PARAMETERS

Gordon [Ref. 8] followed the research effort of Butler to correlate CIP dollars spent on the J-52 engine to improved maintenance parameters at the component level. The major focus of the study revolved around developing a methodology to quantify CIP effectiveness by using existing databases and by maintaining an open dialog with key J-52 managers. He researched Failure Maintenance Actions rather than Mean Flight Hours Between Maintenance Actions as an indicator of engine reliability. The author continued to use the Engine Component

Improvement Feedback Report (ECIFR), as others had done, to track engine performance. Gordon's research efforts, as with those of his predecessors, were unsuccessful in irrefutably tying CIP investments to specific improvements. He was, however, successful in proposing an eight-step procedure to link the observed improvements in a selected maintenance parameter to CIP funding.

Again, Gordon demonstrated that measuring the effectiveness of CIP is a complex and intriguing process complicated by a lack of understanding of various databases, the interactions of numerous, simultaneous improvements on many components, and the complicated coordination between the many activities and offices required to field an ECP.

F. ESTIMATING CHARACTERISTIC LIFE AND RELIABILITY OF AN AIRCRAFT ENGINE COMPONENT IMPROVEMENT IN THE EARLY STAGES OF THE IMPLEMENTATION PROCESS

Martens [Ref. 9] provided the methods and equations for estimating the reliability of a modified component during implementation. The component failure times were assumed to have a Weibull distribution. Since CIP changes are often made through attrition, the complete incorporation into the fleet engine inventory may take ten years or longer. [Ref. 4] The author provided a methodology to estimate reliability of a specific engine component during the early stages of CIP incorporation. However, Martens concluded that reliability estimates could not be made until at least one failure of the component had occurred.

G. AN ANALYSIS OF THE COSTS AND BENEFITS IN IMPROVING THE J-52 FUEL PUMP MAIN GEAR SPLINE DRIVE UNDER THE AIRCRAFT ENGINE COMPONENT IMPROVEMENT PROGRAM (CIP)

Jones [Ref. 10] continued the research of Butler and Gordon on the J-52 engine. The main objectives of Jones were to develop a methodology for extracting useful maintenance data from the NALDA system and to determine the financial Net Present Value and Breakeven Point for one ECP for one J-52 component. The author concluded that numerous databases required extensive manipulation in order to acquire useful data. Jones extensively and laboriously collected the costs of, and maintenance performed on one small low cost, low failure rate component.

Because of the limited scope of his study, the author cautioned about drawing inferences from the thesis about the effectiveness of CIP. However, the insights provided by Jones serve as a baseline from which other research can benefit. He was also successful in identifying the CIP funding associated with the development of a Power Plants Change (PPC).

H. AN ANALYSIS OF THE COSTS AND BENEFITS IN IMPROVING THE T56-A-427 INTERCONNECTOR HARNESS END AND MATING THERMOCOUPLE END CONNECTOR UNDER THE AIRCRAFT ENGINE COMPONENT IMPROVEMENT PROGRAM (CIP)

Murphy [Ref. 11] followed the methodology of Jones to determine the cost effectiveness of one CIP effort for one component on the T56 engine. Murphy validated Jones' approach to data collection and net present value and break-even analysis. Murphy, like Jones, painstakingly detailed the CIP funding process and explained the methodology for extracting maintenance data.

This thesis focuses on the CIP effort on a uniquely different engine, the F402. This author will apply the methodology of previous research efforts, as much as feasible, in this thesis.

III. BACKGROUND

The purpose of this chapter is to briefly familiarize the reader with the F402 engine to provide a background for understanding the effects of a CIP effort on High Pressure Turbine, Second Stage (HPT-2) blades. This chapter also provides the logic behind the process for selecting the HPT-2 blades as a candidate for study. Included is a chronology of events tracing the history of Power Plants Change 159 to demonstrate how the issue has developed into current circumstances. The last section of the Chapter describes the methodology for collecting maintenance data concerning PPC 159.

A. TECHNICAL DESCRIPTION OF THE HARRIER'S F402 ENGINE

The Harrier is a unique platform, being a Vertical/Short Take off and Landing (V/STOL) aircraft. The AV-8B requires an engine specifically designed to enable thrust to be vectored to meet the requirements of both V/STOL and normal flight. The F402 uniquely incorporates:

- Contra-rotating high pressure and low pressure spools (to minimize gyroscopic couple).
- Equal thrust to front and rear exhaust nozzles. Nozzles swivel for vectored thrust.
- High pressure air bleed for aircraft reaction controls.

• Plenum chamber burning and water injection for thrust augmentation.

The F402 engine has undergone evolutionary changes in the last decade. Table 3.1 illustrates F402 engine redesignations since 1984. [Ref. 12] Redesignations are effected through Power Plants Changes.

Table 3.1. F402 ENGINE REDESIGNATIONS

Engine Model	Redesignated to	Date Redesignated	PPC Issued
F402-RR-404	F402-RR-406	1984	unavailable
F402-RR-406	F402-RR-406A	03 Dec 1987	127
F402-RR-406A	F402-RR-406B	30 July 1993	178
F402-RR-406B	F402-RR-408 (interim)	Not released	167
F402-RR-408 (interim)	F402-RR-408A	Not released	169 & 182
F402-RR-408A	F402-RR-408	Not released	183 & 185

The engine models do not change immediately with the issue of a PPC. Rather, engines migrate to a new model when a baseline of modifications, inspections, and repairs are performed to the existing engines during Depot and Intermediate level maintenance. For example, PPC 178 says that a "406A" engine is redesignated "406B" once PPC's 128, 137, 139, 152, 159, 160, 168, 172, and 176 have been incorporated into the "406A." [Ref. 13] As of April 1994, the F402 inventory consists of six "404s," 225 "406As," three "406Bs," and 79 "408s." [Ref. 14] This thesis focuses on the F402-RR-406A engine model because there are few "404's"/"406B's" and because the "408's" have incorporated a completely different single crystal blade made of "CMXS-4" material. Also, no CIP money has been spent on the "408." The author further selected the "406A" model engine for analysis as this model was the only F402 model which presented a sufficient service life (1987 to 1994) for before-and-after collection of maintenance data.

The F402 is comprised of Low pressure (LP) and High Pressure (HP) turbine cases, an intermediate case, a turbine case assembly, and an exhaust diffuser assembly (see Figure 3.1).

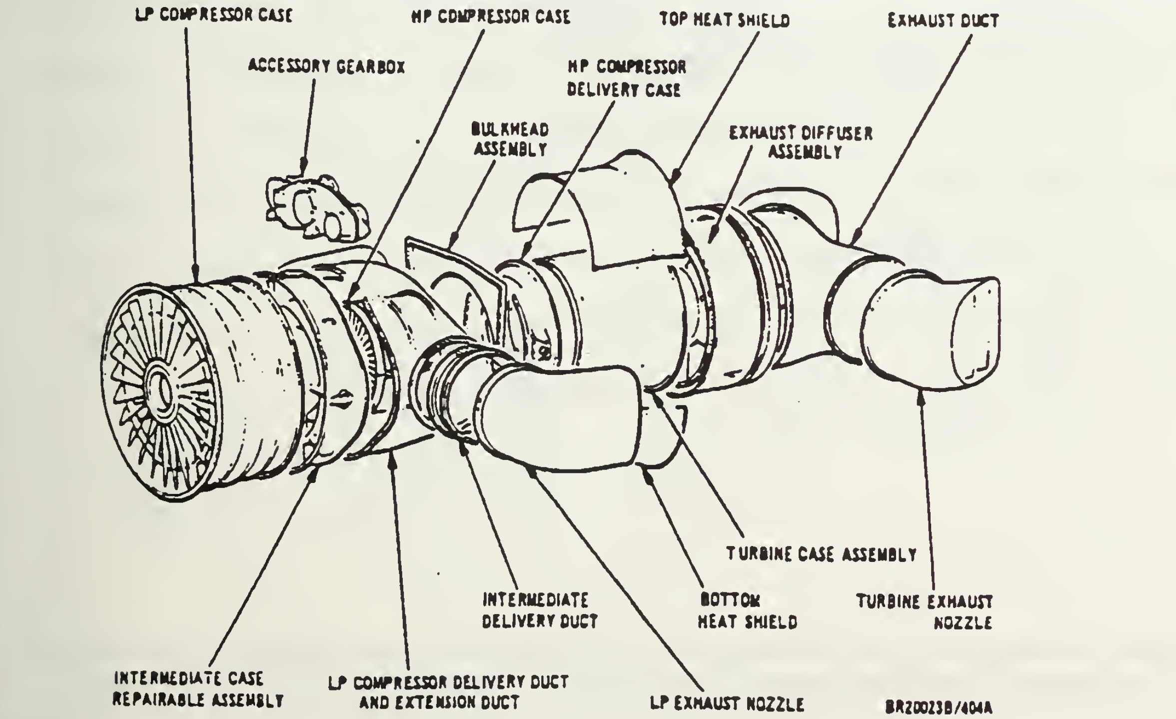

Figure 3.1. F402 Engine and its Main Components

There is no mechanical connection between the co-axial LP and HP rotating assemblies. Combustion takes place in an annular vaporizing type combustion chamber and the gases are expanded across the HP and LP turbines, each of which has two stages. The "hot section" (which is germane to this thesis) consists of the Low Pressure Turbine Stage 1 (LPT-1), the Low Pressure Turbine Stage 2 (LPT-2), the High Pressure Diaphragm Stage 2 (HPD-2), the Combustion Chamber Case Assembly, the High Pressure Turbine Stage 1 (HPT-1), and the High Pressure Turbine Stage 2 (HPT-2). The High Pressure Turbine, Second Stage assembly contains a rotor with 109 blades. Figure 3.2 is the Illustrated Parts Breakdown (IPB) for the HPT-2 module. Part number 6 is the blade which is the focus of this thesis.

The High Pressure Turbine, Second Stage is subjected to both extreme speeds and high temperature. Because of high centrifugal forces at elevated temperatures, the HPT-2 blades undergo stretching, or lengthening, which is known as creep. To promote cooling, the HPT-2 blades have five internal holes passing from the base of the airfoil section to the blade tip. Figure 3.3 illustrates the structure of an HPT-2 blade.

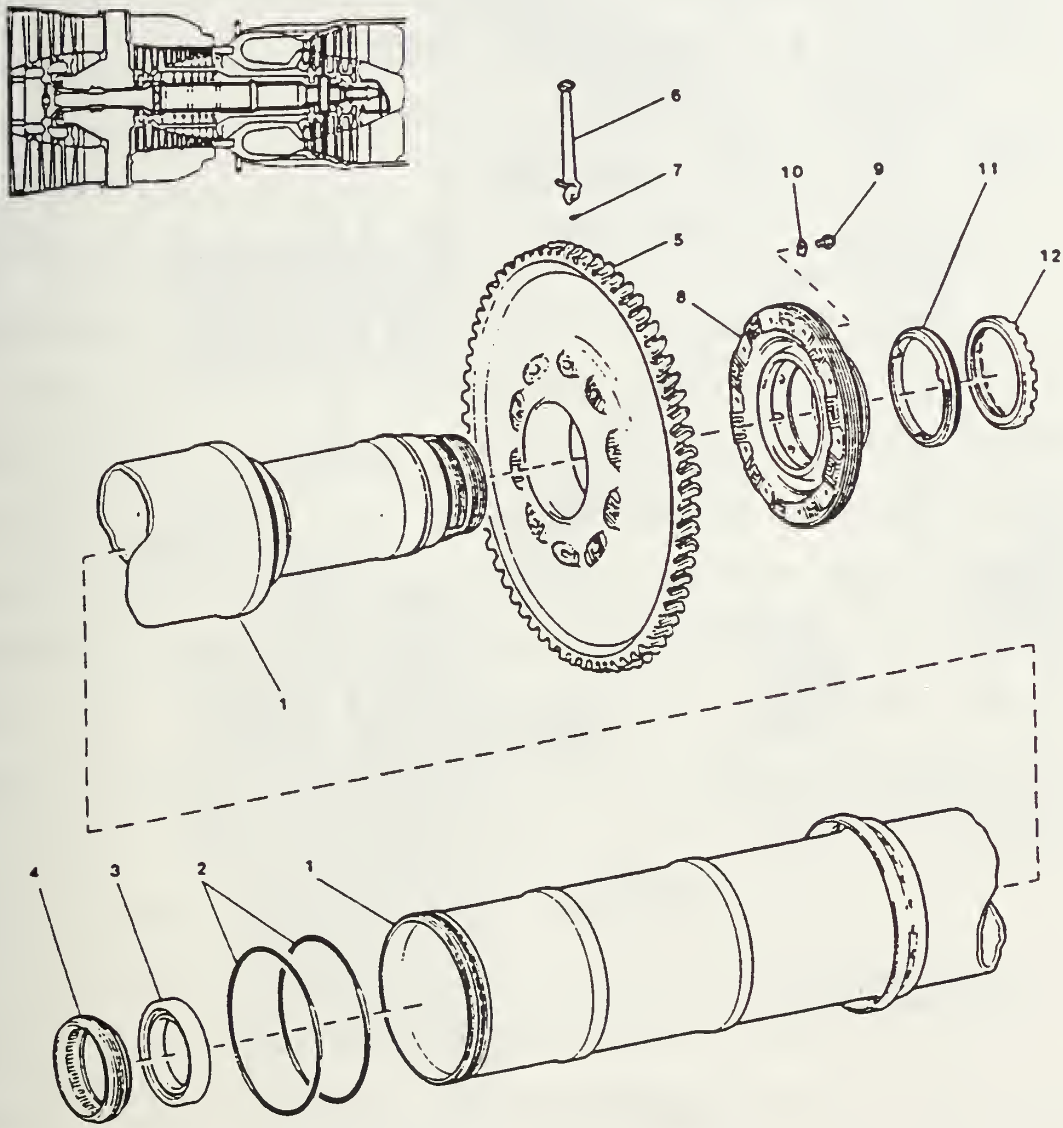

Figure 3.2. High Pressure Turbine, Second Stage Assembly

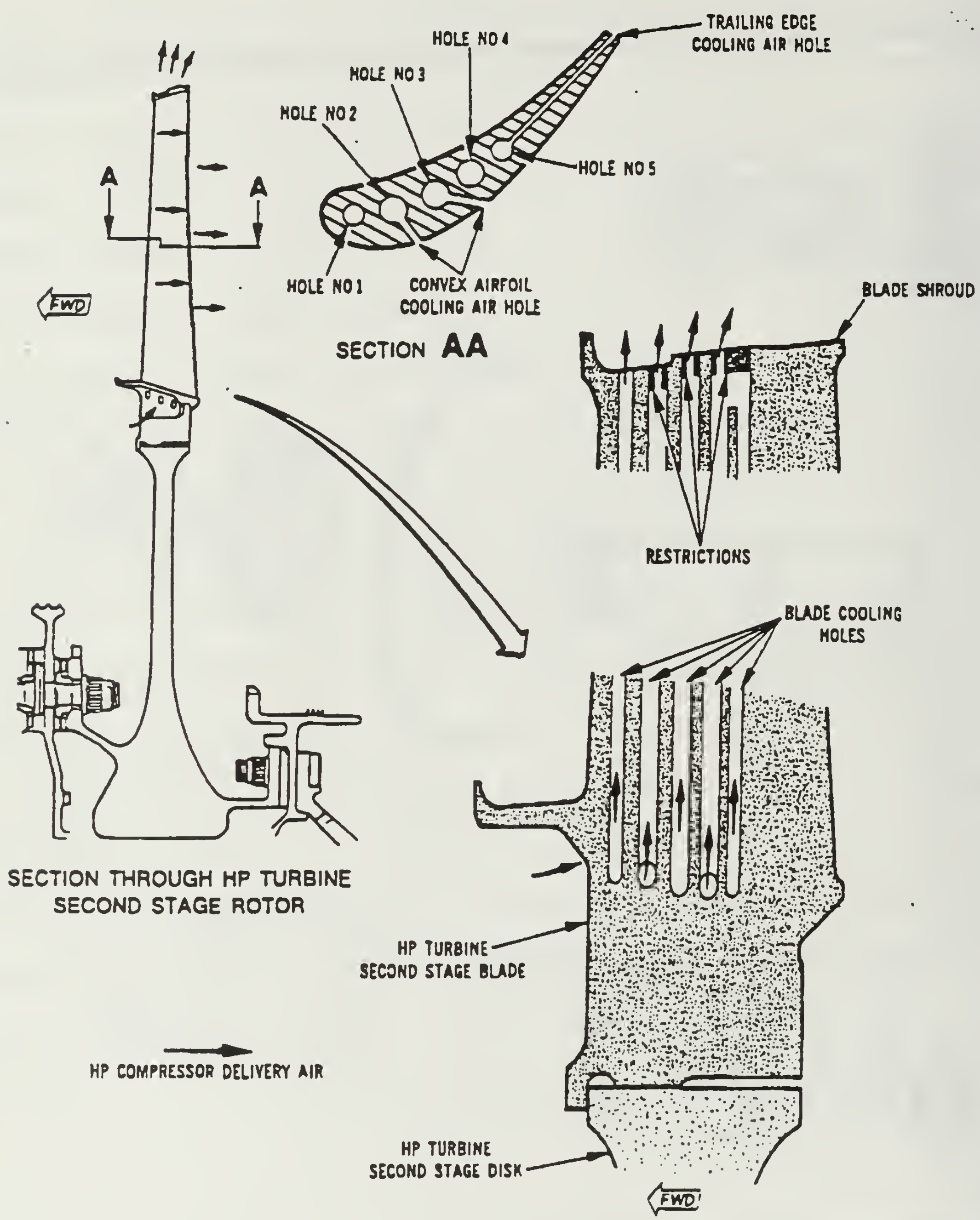

Figure 3.3. Details of High Pressure Turbine, Second Stage Blades

B. CHOOSING THE HPT-2 BLADES AS A CANDIDATE FOR STUDY

Based on the recommendations of Sudol and Price [Ref. 5] and Borer [Ref. 6] to focus at the component level, the author set out to select an F402 component which could be isolated for study. Sudol and Price [Ref. 5] suggested a component selection process based on the historic maintenance data contained in the Engine Component Improvement Feedback Report (ECIFR). Gordon [Ref. 8] also recommended beginning the component selection process by noting improvement trends in maintenance parameters in ECIFR reports.

The author first collected and analyzed ECIFR reports from 1986 through 1993 for the F402 to ascertain maintenance parameter trends. From the ECIFR reports JETMF34N, entitled "Maintenance Actions And Manhours By Work Unit Code" and JETMF200, entitled "Non-Mission Capable (NMC) Hours by Work Unit Code," the author selected several "maintenance drivers" (major causes for maintenance) for further analysis.

Nelson [Ref. 4] stated that "Depot costs are the largest part of operating and support costs." Previous CIP research by Jones [Ref. 10] and Murphy [Ref. 11] concentrated on low impact components that were serviced at the intermediate and organizational levels of maintenance. However, Jones [Ref. 10] recommended studying a critical, high-cost component. Because CIP efforts for components serviced at the depot level offer the greatest potential for benefits, the author searched for a component for study which required Depot level maintenance.

Through examination of numerous PPCs maintained at NAVAIR, and through an open dialog with the F402 Engine Manager, it was determined that PPC 159 (HPT-2 blade improvement) would make an ideal CIP effort for research. Power Plant Change 159 was selected for study because it was:

1. Concerned with an improvement at the component level.

2. Involved with a component that was a "maintenance driver" as revealed from ECIFR reports.

3. Concerned with a component to a F402-RR-406A engine model.

4. Addressed a component serviced at the depot level of maintenance. HPT-2 blades are assigned a Source Maintenance & Recoverability (SM&R) code of PADZZ which means they are removed and replaced only at the depot level.

5. Sufficient before and after maintenance data was available to allow evaluation of the benefits of the CIP effort and maintenance data was available from 1987 to 1994. Power Plant Change 159 was approved on 19 October 1991.

HPT-2 blades were further selected for study because PPC 159 aimed directly at achieving the major benefits of CIP which are: [Ref. 4]

1. Quickly solving safety-of-flight problems which results in reduced aircraft attrition.

2. Correcting service-related deficiencies, which reduces unscheduled engine removals and the spare engines and parts required in the field.

3. Extending the interval between depot overhauls, which reduces operating and support costs.

HPT-2 failures had resulted in at least one catastrophic aircraft loss. [Ref. 15] Furthermore, HPT-2 blade failures were the leading cause of unscheduled "406A" engine removals. [Ref. 16] Power Plant Change 159 also aimed at extending the time period between Depot overhauls. Prior to Power Plant Change 159, the F402-RR-406A historically had a scheduled Major Engine Inspection (MEI), or Depot overhaul, every 500 flight hours, but had achieved only an average operating time of 250 flight hours between removal for Depot level inspections. [Ref. 17] HPT-2 failures and frequent scheduled maintenance were major contributors to premature MEI's. [Ref. 17]

C. BACKGROUND FOR POWER PLANT CHANGE 159

Table 3.2 provides a brief history of HPT-2 blades.

TABLE 3.2 HPT-2 BLADE HISTORY

DATE	DETAILS
1987	F402-RR-406A enters service. HPT-2 blades have unlimited life. [Ref. 18]
08 OCT 88	Aircraft 162952 crashes. Crash is caused by HPT-2 blade failures (creep). Engineering analysis showed blades could not safely operate past 750 hours Time Since New (TSN). [Ref. 15]
01 NOV 88	Power Plant Bulletin (PPB) 60 is issued to locate/identify all high-time HPT-2 blades and all blades with unknown TSN.
10 NOV 88	PPB 61 is issued to remove all high-time HPT-2 blades from service. It introduces 750 hour-limit on 16 engines with used blades.

29 NOV 88	Unlimited HPT-2 blade life is reduced to 1000 hour life limit. HPT-2 blade growth limit is reduced from .005 inch to .0025 inch. Engine model "404A" blades could not be reused. Blades damaged by creep can not be reworked.
JAN 90-DEC 91	Forty engines experience HPT-2 blade failures with significant secondary damage.
JUL 90 - JAN 91	Desert Storm highlights continued problems with HPT-2 failures. 18 blades experience problems during this time period. Hazardous Material Reports (HMRs) concerning blades issued from AV-8B units deployed to Desert Storm.
01 FEB 91	Weibull analysis by both Rolls-Royce and NADEP Cherry Point showed that HPT-2 blade could be expected to fail at less than 500 hours with probability of blade failures increasing with blade time. 500-hour life limit on HPT-2 blades introduced to reduce blade failures. One hundred percent blade replacement at 500 hours is required if blades are available. There are no reliable methods for determining blade serviceability in relation to creep life.
19 FEB 91	ECP 3520R is introduced to change blade material from Nimonic 115 to single crystal ("RR200" material).
19 OCT 91	Power Plant Change 159 is issued. Nimonic blades are to be replaced on an attrition basis (as HPT-2 assemblies arrive at the Depot for regular scheduled/unscheduled maintenance) with single crystal blades.
09 MAR 93	Post PPC 159 blades inspection interval raised to 1000 hours.

D. MAINTENANCE DATA COLLECTION DIFFICULTIES

1. Work Unit Code Changes

Because of the dynamic nature of the F402 engine, the author found it difficult to collect maintenance data from available sources without first selecting and isolating an engine model and component. This difficulty was caused by changing Work Unit Codes (WUC's) for the F402 engine.

Work Unit Codes provide a standard identification system for the Maintenance Data Collection System (MDCS) and are the basis for researching historical maintenance data through the Navy Maintenance and Material Management (3-M) Information System. According to Mr. Bob Kahoun, the Work Unit Code Manager, Naval Technical Services Facility (NATSF), Work Unit Codes for F402 engines have been modified coinciding with redesignations of engine models. [Ref. 19] Work Unit Code series 27200 was carried over from the F402-RR-404 engine to the F402-RR-406 engine in 1984. In 1985, WUC series 27200 changed to series 27600. In 1987, the F402 engine maintenance plans were rewritten to reflect transition to the "406A" model engine which included not only a change in the WUC series from 27600 to 27900, but a completely different WUC breakdown for the fourth through seven WUC positions (which identify assemblies, components, and sub-components). For example, it was revealed that the WUC for HPT-2 assemblies changed from 2723520 to 2763520 (in 1985) to 2797300 (in 1987). Further complicating the research effort, WUC series 27600 has been reassigned to the CFM-56-2A-A engine model used on the E-6 aircraft. Work Unit Code series 27A000 has been assigned to the "408" model engine with 27A500 being assigned to the High Pressure Turbine section.

2. Part Number Changes

Pursuing maintenance parameter changes by part number through the maintenance data bases without first selecting and isolating an engine model/component can also be difficult. One component can be identified by several part numbers. Furthermore, once a Power Plant Change has been fielded, the component of interest may be changed or replaced by the PPC. This new component can also be identified by several part numbers. For example, the part numbers for HPT-2 blades before PPC 159 were B936283 or B936285 or B936287, interchangeably. After PPC 159, the part numbers for the blades were B511764 or B513175.

3. Maintenance Data Sources

The author was interested in investigating both the NALDA data base as Jones [Ref. 10] and Murphy [Ref. 11] had done, and the NAMSO data base as Jones [Ref. 10] had recommended. Both of these data bases are derived from input from Organizational and Intermediate maintenance activities, and the author was interested in determining their usefulness and validity concerning research into PPC 159.

a. NAMSO Data

The author visited the Navy Maintenance Support Office (NAMSO) at the Naval Sea Logistics Center (NSLC) in Mechanicsburg, Pennsylvania, to collect and analyze maintenance data pertaining to the High Pressure Turbine, Second Stage. NAMSO is the central data bank for aviation 3-M data and utilizes 3-M data to produce management information reports which are used throughout the naval establishment. NAMSO also maintains hundreds of different management information reports on microfiche dating from 1965 to the present and can produce "customized" reports if requested.

Mr. Clarence Cupp, Code N63P at NSLC assisted the author in collecting 3-M maintenance data. Because of changing Work Unit Codes and part numbers, the author found it burdensome to manually collect maintenance data from the microfiche. Instead, Mr. Cupp suggested that the author request a computer generated Reliability and Maintainability Summary (RAMS) which summarizes maintenance actions by quarter (by WUC) for selected equipment. The data collected from this report is redundant to the data contained in the microfiche, but the RAMS report is specific to the component of interest and is user friendly.

b. Depot Level Data

The author also visited the Naval Aviation Depot (NADEP) Cherry Point, which is the Cognizant Field Activity (CFA) for the F402 engine, for the purpose of collecting maintenance data pertaining to HPT-2 blades. The author discovered that since HPT-2 blades are a "high impact" and high cost item, historical data concerning the blades was available in NADEP's local records. The Depot had maintained published reports and "briefing papers" pertaining to engine/design problems (with historical records) which included HPT-2 blade difficulties. The published reports are detailed and comprehensive. For example, one published report detailed HPT-2 blade failures from October 1988 to November 1992 by blade serial number and included Time Since New (TSN) and Time Since Hot End Inspection (TSH) for each failed blade. [Ref. 20] The "briefing papers" are concerned with F402 MEI extension initiatives (including HPT-2 improvements) and F402 engine program management decisions. Also, the author was given a report, written by the F402 Lead Engineer, which contained a cost/benefit analysis of several CIP efforts (including a primary evaluation of PPC 159) which led to the "406B" engine. [Ref. 21]

c. *Intermediate Level Data*

The author next visited Marine Aviation Logistics Squadron 14 (MALS-14), at Marine Corps Air Station Cherry Point, North Carolina. This Squadron performs intermediate maintenance on aircraft (including the AV-8B) assigned to Marine Aircraft Group 14 (MAG-14). As was the case at NADEP Cherry Point, MALS-14 maintains local records concerning HPT-2 blades because the blades were a significant problem and readiness degrader. For example, Rolls-Royce field representatives, located with MALS-14, are keeping running records for each engine (with and without PPC 159 incorporated) including TSH and TSN for HPT-2 assemblies. The author acquired similar records from Rolls-Royce representatives located with Marine Aviation Logistics Squadron 13, Marine Corps Air Station Yuma, Arizona.

d. NALDA System Data

Finally, the author visited LCDR Keith Harpe, the Fleet Information Manager at the Naval Air Systems Command (NAVAIR), Washington DC, to collect information from the NALDA system. The author was interested in obtaining condensed, user friendly, information derived from the NALDA system from the SYS Company, Crystal City, Virginia, as Murphy [Ref. 11] had done. SYS is the company that produces the ECIFR reports and is capable (through in-house COBAL programs) of summarizing vast data contained in the NALDA system into user friendly formats. LCDR Harpe contacted Mr. Bob Weaver of SYS who produced several "summarized" reports for the author from the NALDA data base for the time period from 1986 through 1993.

e. NAVAIR Data

While at NAVAIR, the author was also able to obtain "briefing papers," which included historical data concerning

PPC 159. Mr. Jim Carroll, the F402 engine manager and Mr. Steve Clark, the F402 Assistant Program Manager, Logistics (APML), assisted the author in interpreting the cost/maintenance data included in the papers.

f. VAMOSC Data

As Jones [Ref. 10] and Murphy [Ref. 11] had done, the author collected Intermediate and Organizational labor rates from the Visibility and Management of Operations and Support (VAMOSC) data base. Mr. Phil Rodgers at the Naval Center for Cost Analysis (code NCA-66) assisted the author in obtaining VAMOSC data.

g. NAMSO and NALDA Data Dissimilarities

The NALDA database and the Naval Maintenance Support Office (NAMSO) database are both fed maintenance information from the Visual Information Display/ Maintenance Action Forms (VIDS/MAF's) filled out at the Navy's aviation maintenance sites. Information from these forms are entered into the Naval Aviation Logistics Command Management Information System (NALCOMIS). The NALCOMIS feeds VIDS/MAF information directly to the NALDA database on a real-time basis. Therefore, similar maintenance data should be available from both the 3-M and NALDA data bases. Although the consolidated reports obtained from both the NAMSO (3-M) and NALDA data bases were tailored and user friendly, the data contained in the reports was not similar. Therefore, the author did not have confidence in using data for analysis from either the NAMSO or NALDA reports. Moreover, the data from either report did not correspond to the data contained in NADEP Cherry Point's local records. The data from the SYS reports was especially suspect as the initial reports showed failures for the new (post PPC 159) HPT-2 assembly (Part number: B505102) before PPC 159 was approved. The author was told that the old and new assembly part numbers were reversed on the reports and that there was a "glitch" in the system. [Ref. 22] Time constraints did not allow the author to further investigate why the data bases did not match. Perhaps the author did not correctly specify input parameters when requesting computer runs or the different F402 WUC's contributed to the dissimilarity between data sources.

The author believes that data maintained for HPT-2 blades at NADEP Cherry Point and at MALS-14/MALS-13 is valid. These maintenance activities are closely involved with HPT-2 problems and are charted to keep accurate account of blade hours to ensure safety-of-flight.

IV. PRESENTATION OF BEFORE AND AFTER LIFE-CYCLE COSTS

A. BACKGROUND

This chapter presents the life-cycle costs associated with HPT-2 blades for F402-RR-406A model engines before and after the incorporation of Power Plant Change 159. The results will be used in the cost-benefit analysis in Chapter V. This chapter presents three models. The first model displays the life cycle costs of HPT-2 blades as if PPC 159 was not incorporated. Because only 101 of 225 engines (45%) have had PPC 159 incorporated [Ref. 12], and because there have been relatively few hours on the new blades with no failures, it is difficult to accurately assess the reliability of the new blades. Therefore, the second and third models will be presented to show a possible range of life-cycle costs for the fleet of "406A" engines with PPC 159 incorporated. The second model will show the low limit of the range of life-cycle costs while the third model will show the upper limit of the range.

The second model assumes a 750-hour Hot Section Inspection (HSI) interval with 100% replacement of the single crystal blades during the HSI. The Hot Section Inspection interval can be considered the scheduled maintenance interval. The "406A" currently has an HSI interval of 500 hours. HPT-2 blades are the major restriction to an increased HSI interval, and both the F402 Engine Manager and Lead Engineer feel confident that the HSI can be increased to at least 750 hours with the incorporation of PPC 159 to "406A" engines. [Refs. 23, 24] As a consequence, the "406B" (which has PPC 159 incorporated) has an HSI interval of 750 hours. [Ref. 13]

Single crystal blade reliability to date supports at least a 750-hour HSI as 71 engines (with PPC 159 incorporated) have registered an average of 250 flight hours per engine without failure. Of the 71 engines, nine have registered over 400 hours. [Refs. 25, 26] One engine, with PPC 159 incorporated, has reached 500 hours and its HPT-2 assembly was inspected at the Cognizant Field Activity and was found to be in "like new" condition and deemed good for another 500 hours without inspection. [Ref. 27] As a result, the inspection interval for single crystal HPT-2 blades has been raised from 500 to 1,000 hours. [Ref. 28]

The third model assumes an HSI interval of 1,500 hours with 80% of the blades replaced during the HSI. The F402 Engine Manager has expressed optimism that the introduction of single crystal blades could lead to a 1,500-hour inspection interval. [Ref. 23] Furthermore, accelerated bench testing by Rolls-Royce reveals that the single crystal blades are 800% more creep resistant than the nimonic blades. [Ref. 29] Rolls-Royce's Engineering Change Proposal states that the single crystal blades should experience at least a 1,000-hour service life which could be further extended. However, the ECP also states that the single crystal blades are subject to oxidation/sulfidation and will be rejected for this reason rather than creep. The ECP projects that 80% of the blades will require replacement during inspections after 1,000 hours (individual blades can be tracked by blade serial number).

For the three models presented in this chapter, the author assumes an operational life of "406A" engines to extend through the year 2006. This operational life is supported by Mr. Steve Clark, the F402 Assistant Program Manager (Logistics). [Ref. 30] The historical (1992 to 1993) and projected (1994 to 2006) costs are presented in "then year" dollars to aid in the analysis to be done in Chapter V.

B. LABOR, MATERIAL, AND TRANSPORTATION RATES

As mentioned above, the author acquired Intermediate and Organizational labor rates from the Visibility of Management of Operations and Support (VAMOSC) data base. The author assumed an 8% annual increase in the labor rate as this was the mean increase of the Intermediate level and Organizational level labor rates in the data base (1990 to 1992). The author acquired Depot labor rates from NADEP Cherry Point's Level Schedule Repair Program document. The author assumed that the 8% yearly increase for "I" and "O" labor rates would be suitable for Depot labor rates. The author used the Consumer Price Index annual increase of 4% (1990 to 1992) to determine increases in material and transportation costs.

C. AIRCRAFT/ENGINE DATA

Historical AV-8B Class A mishaps are displayed in Table 4.1. [Ref. 23] This table does not include the five combat losses of AV-8Bs during Desert Storm in 1991.

Table 4.1 HISTORICAL AV-8B MISHAPS

YEAR	86	87	88	89	90	91	92	93
MISHAPS	3	4	5	6	11	5	8	4

Table 4.2 provides the actual (1992 to 1993) and estimated (1994 to 2006) yearly fleet of AV-8B aircraft with "406A" engines installed as well as the total yearly inventory of "406A" engines and the PPC 159 installation rate.

Using the historical aircraft accident data, the author calculated a .03 crash rate per aircraft in service. This rate is assumed to be independent of PPC 159. This assumption seems valid as only one accident was caused by nimonic HPT-2 blade failure and no accidents have been caused by single crystal HPT-2 blade failures. Column 1 reflects projected

Table 4.2. F402 AIRCRAFT AND ENGINE ATTRITION, TRANSITION, AND PPC 159 INCORPORATION.

YEAR	COLUMN 1 AIRCRAFT/ ENGINE ATTRITION	COLUMN 2 AIRCRAFT/ ENGINE TRANSITION	COLUMN 3 AIRCRAFT/ ENGINE TOTAL REDUCTIONS	COLUMN 4 AIRCRAFT INVENTORY	COLUMN 5 ENGINE INVENTORY	COLUMN 6 ENGINES WITH PPC 159 INSTALLED	COLUMN 7 PERCENT AIRCRAFT AND ENGINES WITH PPC 159
1992	8		8	158	237	46	19.41%
1993	4		4	150	229	91	39.74%
1994	4		4	146	225	136	60.44%
1995	4	4	8	142	221	221	100.00%
1996	4	4	8	134	213	213	100.00%
1997	4	4	8	126	205	205	100.00%
1998	4	12	16	118	197	197	100.00%
1999	3	12	15	102	181	181	100.00%
2000	3	12	15	87	166	166	100.00%
2001	2	12	14	72	151	151	100.00%
2002	2	12	14	58	137	137	100.00%
2003	1		1	44	123	123	100.00%
2004	1		1	43	122	122	100.00%
2005	1		1	42	121	121	100.00%
2006	1		1	41	120	120	100.00%

attrition based on this ratio except for 1992 and 1993 attritions which are actual.

Column 2 reflects aircraft/engine reductions from the recently introduced "Remanufacturing Program" where some AV-8B "day attack" aircraft will transition to "night attack" aircraft. This transition means that the "406A" engine in the aircraft will be replaced with a "408" engine and that the removed "406A" engine will be retired. Column 2 shows the planned yearly transition. [Ref. 23] Column 3 is the total projected aircraft/engine reductions per year (Column 1 + Column 2). Columns 4 and 5 reflect the beginning year inventories for aircraft and engines, respectively. Actual aircraft/engine inventories are used for 1992 through 1994. Projected beginning year's inventories for future years were calculated by subtracting projected attritions/transitions (that occurred during the previous year) from the previous year's beginning inventory.

PPC 159 is being installed at "the first opportunity" as the "406A" engines are cycled through the depot for needed scheduled/unscheduled maintenance. Because the HSI for nimonic blades was reduced from 1,000 hours to 500 hours in 1991, a high number of HPT-2 rotors were processed through the depot in that year. This created a delay in the subsequent scheduled maintenance cycle (when PPC 159 would be installed). Column 6 reflects the number of "406A" engines with PPC 159 installed. Actual installations are shown for 1992 and 1993 and projected installations are shown for the remaining years.

Column 7 shows the ratio of engines with PPC 159 incorporated to the total inventory of engines. The author assumes that not all of the engines with PPC 159 incorporated will be installed in an aircraft and that the ratio of aircraft and engines with PPC 159 incorporated will roughly be the same. In fact, as of June 1994 only 71 of the 101 engines (71%), with PPC 159 incorporated, have been installed in an AV-8B.

D. INVESTMENT COSTS ASSOCIATED WITH PPC 159

Table 4.3 shows the Research, Development, Testing and Evaluation (RDT&E) and Appropriations Navy (APN) costs which generated PPC 159. Jones [Ref. 10] revealed that the RDT&E costs can be found from the finalized version of the contractor's Engineering Program Notice (EPN). Power Plant Change 159 was actually generated from funding as noted on two EPN's (EPN C133 and EPN C143). Mr. Ted Woodgate, Head Pegasus Projects (United Kingdom), Ministry of Defense, London, England explained to the author that the basic design for single crystal HPT-2 blades for the "406" engine originated in 1988 as a research effort (EPN C133) for the "408" engine. Engineering Program Notice C143 notes the costs of adapting the "408" blades to the "406." [Ref. 31]

Mr. Steve Clark, the Assistant Program Manager (Logistics) for the F402 revealed that Research, Development, Test, and

Table 4.3. PPC 159 INVESTMENT COSTS.

TOTAL COST TO UNITED STATES AND UNITED KINGDOM (IN BRITISH POUNDS STERLING)

(DOES NOT INCLUDE APN COSTS)

YEAR	COLUMN 1 EPN C133 RESEARCH & DEVELOPMENT COSTS	COLUMN 2 EPN C133 BLADE TEST COSTS	COLUMN 3 EPN C143 RESEARCH & DEVELOPMENT COSTS	COLUMN 4 EPN C143 BLADE TEST COSTS	COLUMN 5 TOTAL COSTS EPN C133 &C143
1988	2,620,000		15,000		2,635,000
1989		2,000,000			2,000,000
1990			41,000		41,000
1991				200,000	200,000

TOTAL COST TO UNITED STATES (IN U.S. DOLLARS)

YEAR	COLUMN 6 EPN C133 RESEARCH & MATERIAL COSTS	COLUMN 7 EPN C133 ENGINE TEST COSTS	COLUMN 8 EPN C143 RESEARCH & MATERIAL COSTS	COLUMN 9 EPN C143 ENGINE TEST COSTS	COLUMN 10 TOTAL APN COSTS	COLUMN 11 TOTAL ANNUAL R &D. TESTING & APN COSTS	COLUMN 12 FUTURE VALUE (1992) COEFF	COLUMN 13 FUTURE VALUE (1992)
1988	1,965,000		11,250			1,976,250	1.4641	2,893,428
1989		1,500,000				1,500,000	1.3310	1,996,500
1990			30,750			30,750	1.2100	37,208
1991				150,000	112,610	262,610	1.1000	288,871
								5,216,006

Evaluation for the F402 is jointly funded under the PegasusSupport Program (PSP) by the United States and the United Kingdom with the United States assuming fifty percent of the costs. [Ref. 32]

Columns 1 through 5 present the total (United States and United Kingdom) RDT&E costs for single crystal HPT-2 blades in British Pounds Sterling. Column 1 shows the R&D costs from EPN C133. [Ref. 33] Column 2 shows the costs of blade and engine testing (EPN C133) provided by Mr. Woodgate. [Ref. 31] Column 3 shows the Research and Development costs from EPN C143. [Ref. 34] Column 4 indicates the blade and engine testing (EPN C143) costs provided by Mr. Woodgate. [Ref. 31] Column 5 displays the total annual Research and Development Costs.

After considering the exchange of British pounds to U.S. dollars, columns 6 through 9 present the United States RDT&E costs for single crystal blades and reflect two thirds of the costs of Columns 1 through 4 . The author assumed an exchange rate (the current exchange rate) of 1.5 dollars to the British Pound.

Jones [Ref. 10] discovered that the APN costs for implementation of a Power Plant Change can be found from the Costs and Funding and Milestones chart from the Configuration Change Control Board's (CCCB) approval of the ECP. Column 10 displays the APN costs to implement PPC 159 as detailed in CCCB No. 911-0286. [Ref. 35] Column 11 shows the total U.S. annual RDT&E and APN costs.

Columns 12 and 13 were generated to assist the author in the analysis in Chapter V and are displayed to adjust the costs to a 1992 economic basis. To equate the 1988 through 1991 investment costs to 1992 dollars, a future value factor of 1.10^n was used where n is the number of years into the past from the beginning of 1992. Column 12 shows future value coefficients (assuming a 10% rate). Column 13 shows 1988 through 1991 costs in 1992 base year dollars.

E. LIFE CYCLE COSTS (PPC 159 NOT INCORPORATED)

Tables 4.4 and 4.5 show the actual and estimated life cycle costs caused by HPT-2 maintenance for the fleet of "406A" engines as if PPC 159 was not incorporated.

1. UNSCHEDULED MAINTENANCE

Table 4.4 presents unscheduled life cycle maintenance cost. There were 11 HPT-2 failures in 1990 and 29 failures in 1991, and it was estimated that between 17 and 19 failures per year would continue to occur. [Ref. 21] However, these failures occurred before the 500-hour limit was imposed for the blades. Under the 500-hour limit, it was estimated that blades would fail at the rate of .04 per aircraft in service per year [Ref. 21] and this rate is roughly consistent with actual blade failures since 1991. For example, there were 3 failures out of 126 aircraft (without PPC 159 incorporated) in 1992, 4 failures out of 90 aircraft (without PPC 159) in 1993,

Table 4.4. UNSCHEDULED MAINTENANCE COSTS (PPC 159 NOT INCORPORATED).

	UNSCHEDULED MAINTENANCE						
YEAR	COLUMN 1 UNSCHEDULED EVENTS	COLUMN 2 DEPOT MATERIAL COST/EVENT HPT-2	COLUMN 3 DEPOT LABOR COST/EVENT HPT-2	COLUMN 4 DEPOT MATERIAL COST/EVENT SECONDARY DAMAGE	COLUMN 5 DEPOT LABOR COST/EVENT SECONDARY DAMAGE	COLUMN 6 TOTAL DEPOT COST/EVENT COLS (2 THRU 5)	COLUMN 7 TOTAL DEPOT COSTS COL 6 X COL 1
1992	4	137,131	6,328	166,592	30,992	341,043	1,364,174
1993	6	142,616	6,834	173,256	32,971	355,677	2,134,061
1994	7	148,321	7,381	180,186	35,075	370,963	2,596,740
1995	6	154,254	7,971	187,393	37,180	386,798	2,197,014
1996	5	160,424	8,609	194,889	39,410	403,333	2,161,862
1997	5	166,841	9,298	202,685	41,775	420,598	2,119,816
1998	5	173,515	10,042	210,792	44,281	438,630	2,070,332
1999	4	180,455	10,845	219,224	46,938	457,462	1,866,446
2000	3	187,673	11,713	227,993	49,755	477,133	1,660,424
2001	3	195,180	12,650	237,112	52,740	497,682	1,433,325
2002	2	202,988	13,662	246,597	55,904	519,150	1,204,429
2003	2	211,107	14,755	256,461	59,258	541,581	953,182
2004	2	219,551	15,935	266,719	62,814	565,019	971,834
2005	2	228,333	17,210	277,388	66,583	589,514	990,383
2006	2	237,467	18,587	288,483	70,578	615,115	1,008,788

YEAR	COLUMN 8 INTERMEDIATE LABOR COST/EVENT	COLUMN 9 "O" LEVEL LABOR COST/EVENT	COLUMN 10 TRANS COST/EVENT	COLUMN 11 TOTAL I/O/TRANS COST/EVENT (COLS 8 THRU 9)	COLUMN 12 TOTAL I/O/TRANS COSTS (COL11 XCOL 1)		COLUMN 13 TOTAL UNSCHED COSTS (COL 7+ COL12)
1992	790	2,311	362	3,463	13,854		1,378,027
1993	853	2,496	377	3,726	22,356		2,156,417
1994	921	2,696	392	4,009	28,063		2,624,803
1995	995	2,911	408	4,314	24,504		2,221,517
1996	1,075	3,144	424	4,643	24,886		2,186,748
1997	1,161	3,396	441	4,997	25,187		2,145,003
1998	1,254	3,667	459	5,379	25,391		2,095,724
1999	1,354	3,961	477	5,791	23,629		1,890,075
2000	1,462	4,277	496	6,236	21,700		1,682,124
2001	1,579	4,620	516	6,715	19,339		1,452,663
2002	1,706	4,989	536	7,231	16,777		1,221,205
2003	1,842	5,388	558	7,788	13,707		966,890
2004	1,989	5,819	580	8,389	14,429		986.263
2005	2,149	6,285	603	9,037	15,182		1,005,566
2006	2,320	6,788	628	9,736	15,967		1,024,755

and 3 failures out of 60 aircraft (without PPC 159) to date in 1994. Column 1 displays the projected yearly unscheduled maintenance events (failures) at the rate of .04 failures per aircraft in service. The actual failures for 1992 through 1994 would have been higher had PPC 159 not been incorporated. To determine the additional failures that would have occurred, the author multiplied the assumed failure rate (.04) by the number of aircraft with PPC 159 installed (the product of Column 4 and Column 7 from Table 4.2). These additional projected failures were added to the actual failures and their sum is presented in Column 1.

Column 2 exhibits the Depot level maintenance material cost per event. The 1994 cost per blade is $1,360 and the pins to secure the blade cost $.75 each. [Ref. 36] With 109 blades and 109 pins per HPT-2, the total 1994 material cost per event is $148,321 (1,360 X 109 +.75 X 109).

Column 3 shows the Depot level maintenance labor costs/event. The 1994 Depot Level Schedule Repair Document indicates that it takes 42.3 hours to reblade an HPT-2 at a rate of $174.5 per hour. [Ref. 37]

When an F402 engine experiences an HPT-2 blade failure, both the High Pressure section and the Low Pressure section of the engine experience severe damage. [Ref. 38] Secondary damage occurs to the High Pressure Turbine - First Stage (HPT-1), Low Pressure Turbine - First and Second Stages (LPT-1 and LPT-2), and the High Pressure Diaphragm - Stage 2

(HPD-2). Naval Aviation Depot Cherry Point's study of 21 engines that experienced HPT-2 blade failure indicated that on average $166,592 in material damage above the costs of the HPT-2 itself occurred. [Ref. 20] Column 4 displays this cost.

Column 5 shows the Depot labor costs to repair secondary damage. An average of 201 hours is required to repair secondary damage. [Ref. 38]

Column 6 shows the Depot level costs per event (the summation of Columns 2 through 5). Column 7 displays the total Depot costs per year and is the product of Column 1 and Column 6.

Column 8 displays the Intermediate level maintenance labor costs associated with an HPT-2 blade failure. Approximately 40 hours are required to disassemble and reassemble the Hot Section following an HPT-2 blade failure. This involves replacement of the HPT-2 rotor module, HPT-1 rotor module, HPD-2 diaphragm assembly, LPT-1 rotor assembly, and LPT-2 rotor assembly with spares from "I" level stock. [Ref. 39] The author assumed for the first year (1992) an Intermediate level hourly labor rate of $19.76 which was obtained from the VAMOSC data base (1992).

Column 9 displays the Organizational level labor costs for removing and replacing an engine following an HPT-2 failure. Removing a failed engine and replacing it with an Ready-For-Issue (RFI) spare requires 140.5 hours. [Ref. 40] The author assumed for the first year (1992) an

Organizational level hourly labor rate of $16.45 which was obtained from the VAMOSC data base (1990 to 1992).

Column 10 shows the transportation costs associated with HPT-2 blade failures. When an HPT-2 fails, the HPT-2 (along with the remaining components of the Hot Section which experienced secondary damage) must be transported to the Depot Overhaul Point (NADEP Cherry Point) for repair.

The AEMS data base indicates that approximately 40% (58 of 146 aircraft in 1994) of the inventory of AV-8B aircraft with 406A's installed are located at Marine Corps Air Station (MCAS) Yuma, Arizona, and the remaining 60% are located at MCAS Cherry Point. This installation percentage is very simplistic and does not include aircraft deployed aboard ship or to the Western Pacific under the Unit Deployment Program.

Currently, it costs approximately $980 (full truckload rate) to ship the Hot Section (less the Combustion Chamber Case Assembly which does not experience secondary damage) round trip from Yuma to Cherry Point. [Ref. 41] Because the author was considering costs per unscheduled maintenance event (for aircraft located at both Yuma and Cherry Point) the author reduced this figure by 60% to account for the failures which would occur at Cherry Point (these would incur no transportation cost).

Column 11 shows the total costs (Intermediate, Organizational, transportation) per HPT-2 failure (the summation of Columns 8 through 10). Column 12 displays the total annual (Intermediate, Organizational, transportation) costs per unscheduled event. Column 13 shows the total yearly unscheduled maintenance costs created from HPT-2 failures (Column 7 + Column 12).

2. SCHEDULED MAINTENANCE

Table 4.5 presents scheduled life cycle maintenance costs. Column 1 shows the projected annual flight hours for AV-8B's with "406A" engines installed. A mean of 325 hours per aircraft per year was determined by taking the average annual flight hours per aircraft from ECIFR reports from 1986 to 1992. This estimate is also consistent with the scheduled flight hours for 1994 (55,000 hours scheduled divided by 170 aircraft (146 "406A" engines installed + 24 "408" engines installed)) equals 323.5 hours per aircraft. Column 1 was determined by multiplying the yearly aircraft in service (from Figure 4.1, Column 4) by 325 hours.

Column 2 shows the scheduled maintenance events (number of blade change-outs) per year. The scheduled maintenance events were calculated by dividing the yearly flight hours (Column 1) by 500 (the life of nimonic blades) and then subtracting the number of unscheduled events (Table 4.4, Column 1). The author assumed that HPT-2 blade failures would occur close to the 500 hour blade life. Actual scheduled maintenance events were used for 1992 and 1993 (less the additional unscheduled events that would have occurred had PPC 159 not been

Table 4.5 SCHEDULED MAINTENANCE COSTS (PPC 159 NOT INCORPORATED)

SCHEDULED MAINTENANCE						
	COLUMN 1 YEARLY FLIGHT HOURS	COLUMN 2 SCHEDULED MAINT EVENTS	COLUMN 3 DEPOT MATERIAL COST/EVENT	COLUMN 4 DEPOT LABOR COST/EVENT	COLUMN 5 INTERMEDIATE LABOR COST/EVENT	COLUMN 6 "O" LEVEL LABOR COST/EVENT
YEAR						
1992	51350	42	137,131	6,328	1,976	2,311
1993	48750	39	142,616	6,834	2,134	2,496
1994	47450	39	148,321	7,381	2,305	2,696
1995	46150	87	154,254	7,971	2,489	2,911
1996	43550	82	160,424	8,609	2,688	3,144
1997	40950	77	166,841	9,298	2,903	3,396
1998	38350	72	173,515	10,042	3,136	3,667
1999	33150	62	180,455	10,845	3,387	3,961
2000	28275	53	187,673	11,713	3,657	4,277
2001	23400	44	195,180	12,650	3,950	4,620
2002	18850	35	202,988	13,662	4,266	4,989
2003	14300	27	211,107	14,755	4,607	5,388
2004	13975	26	219,551	15,935	4,976	5,819
2005	13650	26	228,333	17,210	5,374	6,285
2006	13325	25	237,467	18,587	5,804	6,788

					UNSCHEDULED AND SCHEDULED COSTS	
	COLUMN 7 TRANS COST/EVENT	COLUMN 8 D/I/O/TRANS COST/EVENT (COLS 3 THRU 7)	COLUMN 9 TOTAL SCHEDULED COSTS (COL 2 X COL8)		COLUMN 10 TOTAL UNSCHEDULED COSTS (TAB 4 4, COL 13)	COLUMN 11 TOTAL SCHEDULED + UNSCHEDULED (COL 10 + COL 11)
YEAR						
1992	436	148,183	6,223,665		1,378,027	7,601,693
1993	454	154,534	6,026,842		2,156,417	8,183,259
1994	472	161,174	6,285,800		2,624,803	8,910,603
1995	491	168,117	14,562,259		2,221,517	16,783,776
1996	511	175,376	14,335,244		2,186,748	16,521,992
1997	531	182,969	14,062,984		2,145,003	16,207,987
1998	552	190,911	13,741,807		2,095,724	15,837,531
1999	574	199,222	12,395,575		1,890,075	14,285,650
2000	597	207,918	11,034,223		1,682,124	12,716,347
2001	621	217,021	9,531,558		1,452,663	10,984,222
2002	646	226,551	8,015,357		1,221,205	9,236,563
2003	672	236,529	6,348,444		966,890	7,315,334
2004	699	246,980	6,478,296		986,263	7,464,559
2005	727	257,929	6,608,137		1,005,566	7,613,703
2006	756	269,401	6,737,713		1,024,755	7,762,467

incorporated). The 1994 HSI rate is also assumed based on the 1992/1993 rate.

Columns 2 and 3 display the scheduled Depot material costs and Depot labor costs, respectively. As expected, these are the same as the unscheduled Depot costs (Table 4.4, Columns 2 and 3).

Column 4 shows the Intermediate labor costs of a scheduled inspection. At the "I" level, scheduled maintenance takes approximately 100 hours as opposed to 40 hours for unscheduled maintenance. [Ref. 39] The reason scheduled maintenance requires more manhours is that during an HSI, the Combustion Chamber Case Assembly (which does not experience secondary damage from HPT-2 failures) must be removed and inspected. As with unscheduled inspections, a labor rate of $19.76 (1992) increasing at 8% per year was assumed.

Column 6 shows the "O" level costs of removing and replacing an engine which are the same as the unscheduled costs (Table 4.4, Column 9).

Column 7 displays the transportation costs of shipping an Hot Section from Yuma to Cherry Point. Because the entire Hot Section (including the Combustion Chamber Case Assembly) must be transported to Cherry Point for an HSI, the shipping costs are higher for scheduled maintenance than unscheduled. Currently, it costs approximately $1,180 to ship a Hot Section round trip from Yuma to Cherry Point. [Ref. 41] As with unscheduled maintenance, this figure was reduced by 60% to reflect that 40% of the total failures are expected to occur at Yuma.

Column 8 exhibits the total cost per HSI (Depot, Intermediate, Organizational, transportation) which is the summation of columns 3 through 7. Column 9 shows the total annual scheduled costs (the product of Column 2 and Column 8).

Column 10 repeats the unscheduled costs from Table 4.4, Column 13. Column 11 is the sum of the total scheduled and unscheduled costs for HPT-2 blades as if PPC 159 was never implemented (Column 9 + Column 10).

F. LIFE CYCLE COSTS (PPC 159 INCORPORATED) ASSUMING A 750-HOUR INSPECTION INTERVAL

1. SCHEDULED MAINTENANCE COSTS

Table 4.6 shows the actual and projected life cycle costs caused by HPT-2 maintenance (with PPC 159 incorporated) for the fleet of AV-8B aircraft (with "406A" engines installed) assuming a 750-hour HSI with 100% replacement of single crystal blades during inspections. The author also assumed that no unscheduled maintenance (HPT-2 single crystal blade failures) will occur after replacement. The author based this assumption on the fact that there have been no fleet failures of single crystal blades. [Ref. 16] Also, accelerated blade testing by the contractor indicates that the single crystal blades should not fail because of creep. [Ref. 29]

Table 4.6. LIFE CYCLE COSTS (PPC 159 INCORPORATED) ASSUMING A 750-HOUR INSPECTION INTERVAL.

	SCHEDULED AND UNSCHEDULED MAINTENANCE					
	COLUMN 1 SCHEDULED MAINT EVENTS/YEAR	COLUMN 2 DEPOT MATERIAL COST/EVENT	COLUMN 3 DEPOT LABOR COST/EVENT	COLUMN 4 INTERMEDIATE LABOR COST/EVENT	COLUMN 5 O' LEVEL LABOR COST/EVENT	COLUMN 6 TRANS COST/EVENT
YEAR						
1992	43	142,732	6,478	1,976	2,311	436
1993	41	148,441	6,996	2,134	2,496	454
1994	42	154,379	7,556	2,305	2,696	472
1995	85	160,554	8,160	2,489	2,911	491
1996	58	166,976	8,813	2,688	3,144	511
1997	55	173,655	9,518	2,903	3,396	531
1998	51	180,602	10,280	3,136	3,667	552
1999	44	187,826	11,102	3,387	3,961	574
2000	38	195,339	11,990	3,657	4,277	597
2001	31	203,152	12,950	3,950	4,620	621
2002	25	211,278	13,986	4,266	4,989	646
2003	19	219,729	15,104	4,607	5,388	672
2004	19	228,519	16,313	4,976	5,819	699
2005	18	237,659	17,618	5,374	6,285	727
2006	18	247,166	19,027	5,804	6,788	756
	COLUMN 7 TOTAL SCHED COST/EVENT (COLS 2 THRU 7)	COLUMN 8 TOTAL SCHED COSTS (COL 7 X COL 1)	COLUMN 9 UNSCHEDULED EVENTS	COLUMN 10 UNSCHEDULED COST/EVENT TAB 4.4, COL 6 AND COL 11	COLUMN 11 UNSCHEDULED COSTS COL 9 X COL 10	COLUMN 12 SCHED AND UNSCHEDULED COSTS COL 8 + COL 11
YEAR						
1992	153,934	6,619,141	3	344,507	1,033,520	7,652,661
1993	160,521	6,581,379	4	359,403	1,437,611	8,018,991
1994	167,407	7,031,109	3	374,972	1,124,916	8,156,025
1995	174,606	14,841,502				14,841,502
1996	182,133	10,575,832				10,575,832
1997	190,004	10,374,202				10,374,202
1998	198,237	10,136,496				10,136,496
1999	206,849	9,142,740				9,142,740
2000	215,861	8,137,970				8,137,970
2001	225,293	7,029,134				7,029,134
2002	235,165	5,910,486				5,910,486
2003	245,501	4,680,895				4,680,895
2004	256,326	4,776,199				4,776,199
2005	267,663	4,871,465				4,871,465
2006	279,540	4,966,503				4,966,503

Column 1 exhibits the expected number of scheduled Hot Section Inspections per year. The number of HSI's was calculated by dividing the projected flight hours per year (Table 5.5, Column 1) by 750 (HSI interval). Actual HSI's are used for 1992 and 1993. The number of HSI's for 1994 is also assumed based on the 1992/1993 actual rate. Because PPC 159 was installed by first opportunity, and because a delay in scheduled maintenance was caused in 1991 by a nimonic blade inspection interval reduction, the author assumes that remaining nimonic blade replacement (PPC 159 incorporation) will occur in 1995.

Column 2 shows the Depot material cost for HPT-2 inspection and blade replacement. The costs (in 1994 dollars) of single crystal blades are $1,390 each and the cost of retaining wires to secure the blades are $12.64 each. [Ref. 32] There are 109 blades and 227 retaining wires per HPT-2 assembly for a total current material cost per event of $154,379 (109 x $1,390 + 227 X $12.64).

It takes an additional one hour to secure HPT-2 blades with wires rather than pins. [Ref. 42] Depot labor costs are shown in Column 3 (43.3 hours at a rate of $174.5 per hour). Intermediate labor, Organizational labor, and transportation costs (Columns 4, 5, and 6, respectively) are the same as for scheduled maintenance without PPC 159 being incorporated (Table 4.5, Columns 5, 6, and 7).

Column 7 shows the total cost per HSI (the summation of

Columns 2 through 7). Column 8 displays the total annual scheduled costs (Column 1 X Column 7) for HPT-2 blades with a 750-hour HSI. Column 8 displays the total scheduled costs (the product of Column 1 and Column 7).

2. UNSCHEDULED MAINTENANCE COSTS

Column 9 shows the actual failures that occurred from 1992 to 1993. Column 9 also shows the actual failures as of July, 1994 with an additional failure assumed for the remainder of the year. Column 10 exhibits the unscheduled costs per failure (the sum of Column 6 and Column 11 from Table 4.4.) Column 11 shows the total annual costs of unscheduled maintenance and is the product of Column 9 and Column 10. Column 12 is the total unscheduled and scheduled maintenance cost for HPT-2 blades with a 750-hour inspection interval assumed and is the sum of Column 8 and Column 11.

G. LIFE CYCLE COSTS (PPC 159 INCORPORATED) ASSUMING A 1,500-HOUR INSPECTION INTERVAL

1. SCHEDULED MAINTENANCE COSTS

Table 4.7 shows the actual and projected HPT-2 maintenance costs for the fleet of AV-8B aircraft (with "406A" engines installed) assuming a 1,500-hour HSI interval with 80% single crystal blade replacement during inspections. The author also assumed that no unscheduled maintenance (HPT-2 single crystal blade failure) will occur after replacement.

Column 1 shows the scheduled maintenance events per year

Table 4.7. LIFE CYCLE COSTS (PPC 159 INCORPORATED) ASSUMING A 1,500-HOUR INSPECTION INTERVAL.

	SCHEDULED AND UNSCHEDULED MAINTENANCE					
	COLUMN 1 SCHEDULED MAINTENANCE EVENTS/YEAR	COLUMN 2 DEPOT MATERIAL COST/EVENT	COLUMN 3 DEPOT LABOR COST/EVENT	COLUMN 4 INTERMEDIATE LABOR COST/EVENT	COLUMN 5 "O" LEVEL LABOR COST/EVENT	COLUMN 6 TRANS COST/EVENT
YEAR						436
1992	43	142,732	6,478	1,976	2,311	454
1993	41	148,441	6,996	2,134	2,496	472
1994	42	154,379	7,556	2,305	2,696	491
1995	85	160,554	8,160	2,489	2,911	511
1996	29	128,443	8,813	2,688	3,144	531
1997	27	133,581	9,518	2,903	3,396	552
1998	26	138,924	10,280	3,136	3,667	574
1999	22	144,481	11,102	3,387	3,961	597
2000	19	150,260	11,990	3,657	4,277	621
2001	16	156,271	12,950	3,950	4,620	646
2002	13	162,521	13,986	4,266	4,989	672
2003	10	169,022	15,104	4,607	5,388	699
2004	9	175,783	16,313	4,976	5,819	727
2005	9	182,814	17,618	5,374	6,285	756
2006	9	190,127	19,027	5,804	6,788	

	COLUMN 7 TOTAL SCHED COST/EVENT (COLS 2 THRU 6)	COLUMN 8 TOTAL SCHED COSTS (COL 1 X COL 7)	COLUMN 9 UNSCHEDULED EVENTS	COLUMN 10 UNSCHEDULED COST/EVENT TAB 4 4, COL 6 AND COL 11	COLUMN 11 UNSCHEDULED COSTS COL 9 X COL 10	COLUMN 12 SCHED AND UNSCHEDULED COSTS COL 8 + COL 11
YEAR						
1992	153,934	6,619,141	3	344,507	1,033,520	7,652,661
1993	160,521	6,581,379	4	359,403	1,437,611	8,018,991
1994	167,407	7,031,109	3	374,972	1,124,916	8,156,025
1995	174,606	14,841,502				14,841,502
1996	143,599	4,169,165				4,169,165
1997	149,929	4,093,063				4,093,063
1998	156,559	4,002,689				4,002,689
1999	163,505	3,613,451				3,613,451
2000	170,783	3,219,255				3,219,255
2001	178,411	2,783,212				2,783,212
2002	186,408	2,342,531				2,342,531
2003	194,794	1,857,038				1,857,038
2004	203,590	1,896,780				1,896,780
2005	212,818	1,936,643				1,936,643
2006	222,502	1,976,557				1,976,557

and was determined by dividing the projected flight hours (Table 4.5, Column 1) by 1,500 (assumed HSI interval). Actual HSI's were used for 1992 and 1993. It was assumed that the same PPC 159 incorporation schedule would be followed in 1994 and 1995 for a 1,500-hour HSI as a 750-hour HSI as scheduled incorporation is based on 500-hour replacement of the nimonic blades. Column 2 shows the Depot material costs per event. Through the incorporation of PPC 159, 100% replacement of the nimonic blades with single crystal blades would be required. Once the incorporation of PPC 159 is complete (again the author assumed that incorporation will be complete in 1995), on the average 80% of the blades will require replacement during each event (based on the ECP) for a total current cost per HSI of $123,503 (87 blades X $1,390 per blade + 227 retaining wires X $12.64 per wire). All blade retaining wires are required to be replaced during HPT-2 blade scheduled maintenance as each blade must be removed for inspection and pressure washing. [Ref. 28]

Depot labor, Intermediate labor, Organizational labor, and transportation costs (Columns 3, 4, 5, and 6, respectively) remain the same as for scheduled maintenance with a 750-hour inspection interval assumed (Table 4.6, Columns 3, 4, 5, and 6).

Column 7 shows the total Depot, Intermediate, Organizational, and transportation costs per event (the summation of Columns 2 through 6). Column 8 shows the total annual scheduled costs of HPT-2 blades assuming a 1,500-hour HSI interval (Column 1 X Column 7).

2. UNSCHEDULED MAINTENANCE COSTS

Column 9 shows the actual failures that occurred from 1992 to 1993. Column 9 also shows the actual failures as of July, 1994 with an additional failure assumed for the remainder of the year. Column 10 exhibits the unscheduled costs per failure which is the sum of Column 6 and Column 11 from Table 4.4. Column 11 shows the total annual costs of unscheduled maintenance and is the product of Column 9 and Column 10. Column 12 is the total unscheduled and scheduled maintenance cost for HPT-2 blades with a 1,500-hour inspection interval assumed and is the sum of Column 8 and Column 11.

V. ANALYSIS OF THE COSTS AND BENEFITS OF POWER PLANT CHANGE 159

This Chapter analyzes the data presented in Chapter IV. OMB circular A-94 [Ref. 43] requires that investments made by federal agencies be analyzed by both a Net Present Value (NPV) and Break-even analysis. This Chapter also considers some possible additional benefits of PPC 159.

A. NET PRESENT VALUE ANALYSIS

The Net Present Value analysis considers the time value of money and takes the present value of all expected life cycle costs concerning PPC 159 for the F402-RR-406A for the three models derived in Chapter IV. The sum of the present value of all expected costs over the operational life of the "406A" for each model is the model's Net Present Value. The NPV's can then be compared to determine the expected savings (or benefits or costs avoidance) of the different models. The difference between the model with no CIP effort (without PPC 159) and the models with PPC 159 incorporated is the expected benefit of PPC 159 and will be positive if the CIP effort was effective. The author assumed a capital discount rate of 10% as this is the generally accepted rate used by the Department of Defense. For ease of analysis, the author assumed that all costs occur at the end of the year.

Table 5.1 presents the Net Present Value analysis with a base year of 1992. Column 1 is taken from Table 4.5 and shows the total costs as if PPC 159 had not been implemented. Column 2 shows the total costs taken from Table 4.6 (PPC 159 with 750-hour inspection assumed), and also includes the investment costs of PPC 159 (adjusted to an 1992 economic basis). The investment costs for PPC 159 are carried over from Table 4.3, Column 13 for both the 750-hour and 1,500-hour inspection models.

Column 3 displays the total costs taken from Table 4.7 (PPC 159 with 1,500-inspection assumed) and also includes the investment costs of PPC 159 (adjusted to an 1992 economic basis). The column values shown in Table 5.1 were discounted using the discount factor of $1/1.10^n$ where n is the number of years into the future from 1992. The sum of the resulting present values for each year is displayed at the bottom of the columns and is the Net Present Value of each model.

The low limit of the range of savings resulting from PPC 159 is determined by subtracting the NPV of the model assuming a 750 hour inspection (Column 2) from the NPV of the model without PPC 159 incorporated (Column 1). The high limit of the range of savings resulting from PPC 159 is determined by subtracting the NPV of the model assuming a 1,500-hour inspection (Column 3) from the model without PPC 159 incorporated (Column 1). Thus, the Net Present Value analysis shows that the CIP effort for HPT-2 blades will save (avoid costs) between $17,192,871 and $38,639,494 (in 1992 dollars) depending on the reliability of the single crystal blades.

Table 5.1. NET PRESENT VALUE ANALYSIS.

	COLUMN 1		COLUMN 2		COLUMN 3
	WITHOUT		WITH		WITH
	PPC 159		PPC 159		PPC 159
	SCHED &		750- HOUR		1,500-HOUR
	UNSCHED		INSPECTION		INSPECTION
YEAR					
1992	7,601,693		12,868,667		12,868,667
1993	8,183,259		8,018,991		8,018,991
1994	8,910,603		8,156,025		8,156,025
1995	16,783,776		14,841,502		14,841,502
1996	16,521,992		10,575,832		4,169,165
1997	16,207,987		10,374,202		4,093,063
1998	15,837,531		10,136,496		4,002,689
1999	14,285,650		9,142,740		3,613,451
2000	12,716,347		8,137,970		3,219,255
2001	10,984,222		7,029,134		2,783,212
2002	9,236,563		5,910,486		2,342,531
2003	7,315,334		4,680,895		1,857,038
2004	7,464,559		4,776,199		1,896,780
2005	7,613,703		4,871,465		1,936,643
2006	7,762,467		4,966,503		1,976,557
	NPV		***NPV***		***NPV***
	87,252,760		70,059,889		48,613,266
			SAVINGS		***SAVINGS***
			17,192,871		**38,639,494**

B. BREAK-EVEN ANALYSES

A Break-even analysis provides insight into when the savings (benefits) accrued from an investment will equal the costs associated with the investment. To be considered a success, the CIP investment should have a break-even point before the end of the concerned component's operational life. For PPC 159, the break-even point should occur prior to the year 2006. The author also considered the present value break-even point (discount rate of 10%) in his break-even analyses.

Table 5.2 presents the data to be used for the break-even analyses. Column 1 shows the discount factor of $1/1.10^n$ where n is the number of years into the future from the beginning of 1992.

1. WITHOUT PPC 159 COST DATA

Column 2 exhibits the undiscounted costs (PPC 159 not incorporated) taken from Table 4.5, Column 12. Column 3 exhibits the cumulative undiscounted costs. Column 4 shows annual discounted costs for this model (Column 1 multiplied by Column 2). Column 5 shows the cumulative discounted costs. The total cumulative discounted costs equal the model's NPV (from Table 5.1).

2. PPC 159 INCORPORATED, 750-HOUR MODEL COSTS

Column 6 displays the undiscounted costs (PPC 159 incorporated, 750-hour inspection assumed) from Table 4.6, Column 12 with the total value of the CIP investment up to 1992 added (from Table 4.3, Column 13). Column 7 exhibits the cumulative undiscounted costs. Column 8 contains the discounted annual costs. Column 9 is the cumulative discounted costs for this model and is equal to the model's NPV from Table 5.1, Column 2.

3. PPC 159 INCORPORATED, 1,500-HOUR MODEL COSTS

Column 10 shows the undiscounted costs (PPC 159 incorporated, 1,500 hour inspection assumed) taken from Table

4.7, Column 12 with the total value of the CIP investment up to 1992 added in (from Table 4.3, Column 13). Column 11 exhibits the cumulative undiscounted costs. Column 12 displays the discounted costs. Column 10 displays the cumulative discounted costs for this model which is equal to the model's NPV from Table 5.1, Column 3.

Table 5.2 DISCOUNTED AND UNDISCOUNTED COST DATA.

YEAR	COLUMN 1 DISCOUNT FACTOR	COLUMN 2 WITHOUT PPC 159 UNDISCOUNTED	COLUMN 3 WITHOUT PPC 159 UNDISCOUNTED CUMULATIVE	COLUMN 4 WITHOUT PPC 159 DISCOUNTED	COLUMN 5 WITHOUT PPC 159 DISCOUNT CUM	COLUMN 6 PPC 159 750 HR INSPCT UNDISCOUNT	COLUMN 7 PPC 159 750 HR INSPECT UNDISC CUM
1992	0.9091	7,601,693	7,601,693	6,910,699	6,910,699	12,868,667	12,868,667
1993	0.8264	8,183,259	15,784,951	6,762,645	13,673,344	8,018,991	20,887,658
1994	0.7513	8,910,603	24,695,555	6,694,536	20,367,880	8,156,025	29,043,683
1995	0.6830	16,783,776	41,479,331	11,463,319	31,831,199	14,841,502	43,885,185
1996	0.6209	16,521,992	58,001,323	10,258,505	42,089,704	10,575,832	54,461,016
1997	0.5645	16,207,987	74,209,310	9,149,409	51,239,113	10,374,202	64,835,219
1998	0.5132	15,837,531	90,046,841	8,127,821	59,366,934	10,136,496	74,971,714
1999	0.4665	14,285,650	104,332,491	6,664,256	66,031,190	9,142,740	84,114,455
2000	0.4241	12,716,347	117,048,838	5,393,003	71,424,192	8,137,970	92,252,425
2001	0.3855	10,984,222	128,033,060	4,234,417	75,658,610	7,029,134	99,281,558
2002	0.3505	9,236,563	137,269,623	3,237,415	78,896,025	5,910,486	105,192,044
2003	0.3186	7,315,334	144,584,957	2,330,665	81,226,691	4,680,895	109,872,939
2004	0.2897	7,464,559	152,049,516	2,162,483	83,389,173	4,776,199	114,649,138
2005	0.2633	7,613,703	159,663,218	2,004,688	85,393,861	4,871,465	119,520,603
2006	0.2394	7,762,467	167,425,686	1,858,335	87,252,760	4,966,503	124,487,105

YEAR	COLUMN 8 PPC 159 750 HR INSPCT DISCOUNTED	COLUMN 9 PPC 159 750 HR INSPECT DISCOUNT CUM	COLUMN 10 PPC 159 1,500 HR INSPCT UNDISCOUNTED	COLUMN 11 PPC 159 1,500 HR INSPCT UNDISC CUM	COLUMN 12 PPC 159 1,500 HR INSPCT DISCOUNTED	COLUMN 13 PPC 159 1,500 HR INSPECT DISCOUNT CUM
1992	11,698,905	11,698,905	12,868,667	12,868,667	11,698,905	11,698,905
1993	6,626,894	18,325,799	8,018,991	20,887,658	6,626,894	18,325,799
1994	6,127,621	24,453,421	8,156,025	29,043,683	6,127,621	24,453,421
1995	10,136,746	34,590,166	14,841,502	43,885,185	10,136,746	34,590,166
1996	6,566,534	41,156,700	4,169,165	48,054,349	2,588,634	37,178,801
1997	5,856,237	47,012,938	4,093,063	52,147,412	2,310,534	39,489,335
1998	5,202,050	52,214,987	4,002,689	56,150,102	2,054,180	41,543,515
1999	4,265,088	56,480,076	3,613,451	59,763,553	1,685,675	43,229,190
2000	3,451,313	59,931,389	3,219,255	62,982,808	1,365,286	44,594,476
2001	2,709,731	62,641,120	2,783,212	65,766,020	1,072,928	45,667,404
2002	2,071,625	64,712,745	2,342,531	68,108,551	821,057	46,488,461
2003	1,491,333	66,204,078	1,857,038	69,965,589	591,652	47,080,114
2004	1,383,665	67,587,743	1,896,780	71,862,370	549,497	47,629,611
2005	1,282,657	68,870,400	1,936,643	73,799,013	509,918	48,139,529
2006	1,188,981	70,059,889	1,976,557	75,775,570	473,188	48,613,266

4. GRAPHIC PORTRAYAL OF LIFE CYCLE COSTS

In Figures 5.1 and 5.2 the author presents a graphical portrayal of the information in Table 5.2. Figure 5.1 shows a side-by-side annual comparison of the cumulative discounted costs taken from Columns 5, 9, and 13 from Table 5.2. Figure 5.1 clearly shows that the break-even point will occur during 1996 and that the cumulative benefits from PPC 159 increase over the life of the "406A" engines.

Figure 5.2 shows a side-by-side annual comparison of the cumulative undiscounted costs taken from Columns 3, 7, and 11 from Table 5.2. Figure 5.2 again clearly shows that the break-even point will occur during 1996 and that the cumulative benefits from PPC 159 continue to increase over the life of the "406A" engines.

From the Break-even point analysis, the CIP effort for HPT-2 blades can also be considered a success as the investment "paid for itself" early in the life-cycle.

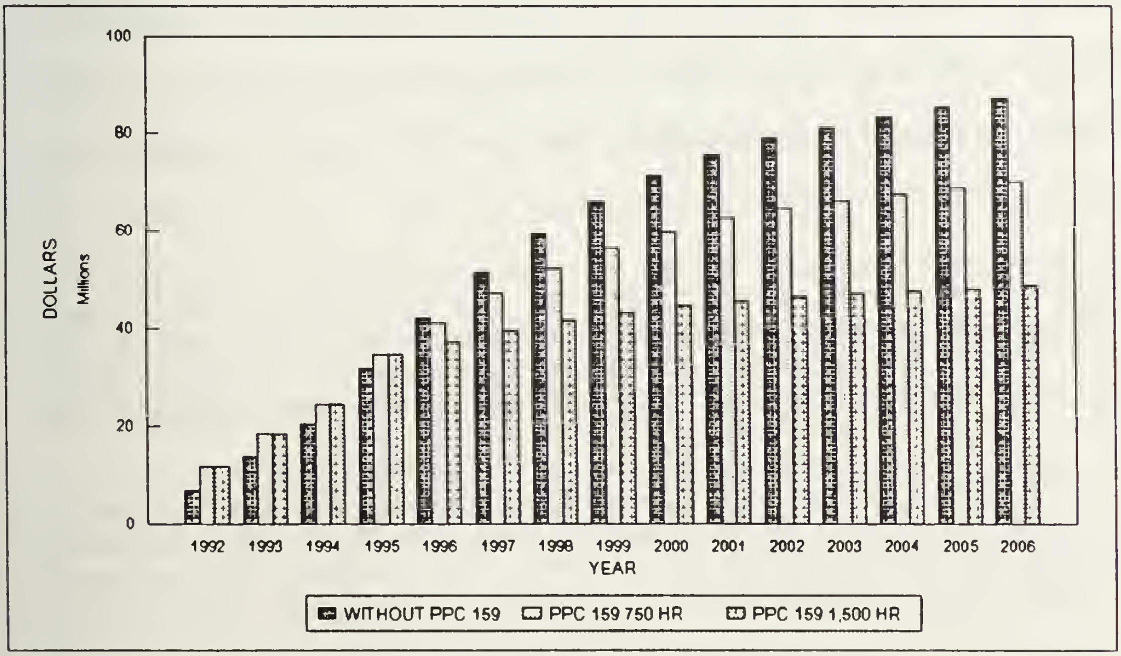

Figure 5.1. Life Cycle Costs (Discounted).

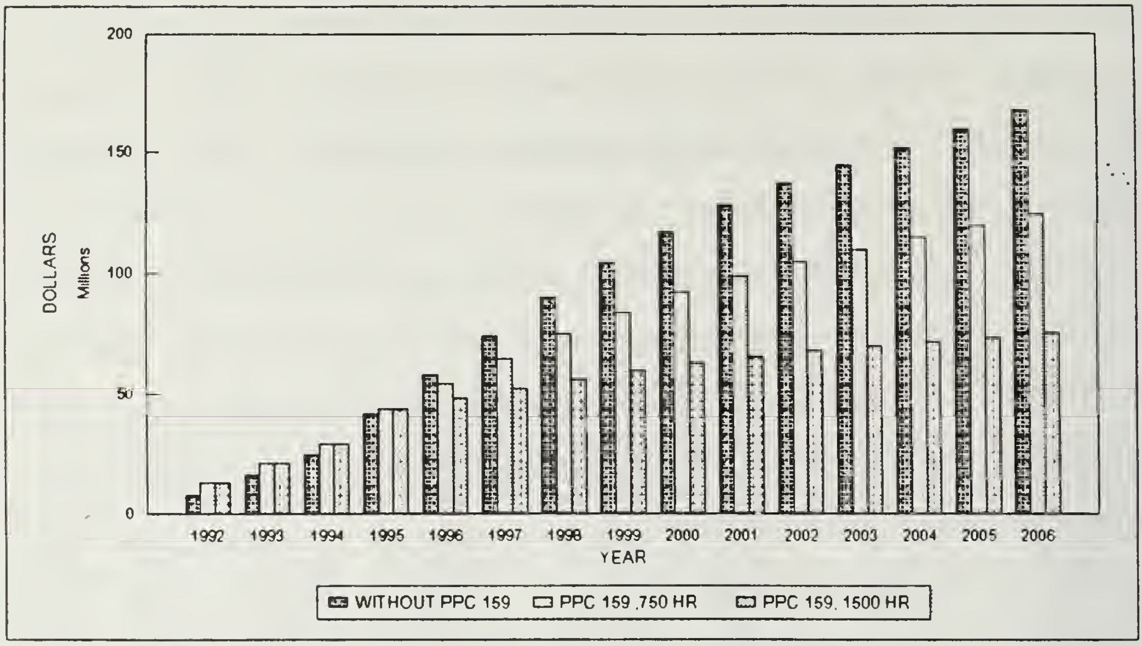

Figure 5.2. Life Cycle Costs (Undiscounted).

C. ADDITIONAL PPC 159 BENEFITS

The author has attempted to make a careful determination of the costs and benefits of Power Plant Change 159. However, the author also believes that PPC 159 may potentially offer additional savings (benefits the author was unable to quantify). These benefits include:

1. Reduced aircraft attrition. If the incorporation of PPC 159 resulted in even one less aircraft crash over the life of the "406A," the CIP venture would pay for itself many times over (with the cost of an AV-8B roughly between $25 million and $30 million).

2. Increased operational availability/readiness. Power Plant Change 159 reduces the frequency that aircraft are down for engine replacement thereby increasing operational availability/readiness.

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The objectives of this thesis were to:

- Examine the data bases available for extracting logistic cost/benefit information concerning the F402 engine and identify problems associated with gathering meaningful information from these data bases.
- Determine the impact of one significant CIP effort for one component on the F402 engine (hopefully as a bellwether of overall CIP cost-effectiveness for the F402).
- Determine whether the component improvement effort for the selected component was, in fact, cost-effective.
- Refine the methodology for analyzing the Component Improvement Program for the F402.

To achieve the objectives of this thesis, Power Plant Change 159 was selected for evaluation. PPC 159 aimed at improving the High Pressure Turbine, Second Stage blades on the F402-RR-406A model engine.

Chapter I provided the nature of the CIP issue and the motivation for CIP research. Chapter I also provided the thesis objectives, scope and organization for study. Chapter II provided a literature review of previous CIP research conducted by the Naval Postgraduate School and the Institute for Defense Analysis. Chapter III oriented the reader to specific background information concerning the F402 engine and Power Plant Change 159. Chapter III further described the reason for choosing PPC 159 for study, a history of HPT-2 blades (to explain how the CIP effort for blades developed), and maintenance data collection problems.

Chapter IV presented both the historic and estimated life cycle monetary costs for HPT-2 blades for the "406A" model engine with and without PPC 159 incorporated. Two incorporation scenarios were considered (because sufficient single crystal blade reliability information was not available). Chapter V presented cost/benefit analyses of PPC 159. These analyses included making comparisons of the models presented in Chapter IV through a Net Present Value analysis and a Break-even analysis.

B. CONCLUSIONS

From the results of the analysis conducted in Chapter V, PPC 159 is clearly cost-effective. The Net Present Value analysis revealed that PPC 159 will save between 17.2 million dollars and 38.6 million dollars depending on the reliability of single crystal HPT-2 blades. The break-even point will occur sometime during 1996 regardless.

Predicting the expected reductions in maintenance and supply support costs as a consequence of an F402 CIP effort is a difficult and intriguing process. Complicating this process is the dynamic nature of the F402 engine program and the corresponding Work Unit Code changes. F402 engine models are frequently changed and result in a narrow time window to collect sufficient maintenance data (both before and after the PPC) from fleet use for cost-benefit analyses. In addition, Power Plant Changes are usually accomplished by first opportunity and may take several years to be fully incorporated. By the time a PPC is fully incorporated, the engine model may change due to another PPC. Further complicating the process is the difficulty in collecting and interpreting maintenance data and in determining the validity of available sources. These issues have been identified by other investigators including Butler [Ref. 7], Gordon [Ref. 8], Jones [Ref. 10], and Murphy [Ref. 11].

Because this thesis only examined one component, the reader is cautioned against interpreting the results of this study as conclusive for every component improved under the CIP program for the F402 engine. Indeed, HPT-2 blades are not really part of the CIP because they are internal rather than external to the engine.

C. RECOMMENDATIONS

The author recommends that a follow-up study concerning PPC 159 be conducted to validate the cost and life cycle benefit estimates produced in this thesis. This follow-up study should be conducted when PPC 159 is fully incorporated and sufficient fleet single crystal blade usage is available (no failures have yet occurred).

The author also recommends that further thesis efforts consider F402 components serviced at the depot level of maintenance. As identified in this thesis, depot labor and material costs are the largest part of the maintenance costs. Further research could possibly lead to a classification scheme based on the extent to which the component under the proposed CIP effort is serviced at the depot level. If depot level repairables offer the greatest potential for life cycle savings, then perhaps engine managers could prioritize (under a constrained budget environment) Engineering Change Proposals according to who (depot, intermediate, organizational) repairs the component.

Also, if depot labor and material costs are the largest part of maintenance costs, then consideration should be given to transferring repair authority of more engine components from the depot level to the intermediate level. Further research could possibly identify F402 components (currently repaired at the depot level) which could be more economically repaired at the "I" level. This issue is currently pertinent as the Department of Defense considers closing the Navy's Depots in favor of granting all fixed-wing depot overhauls (for all the Services) to the Air Force.

Jones [Ref. 10] and Murphy [Ref. 11] both recommended that training in the NALDA system be made available (and take priority) at the Naval Postgraduate School. As a viable alternative to lengthy training at NPS, the author recommends that the customized, user friendly reports produced by the SYS company (produced from NALDA system data) and by NAMSO (produced from 3-M data) be further pursued to determine their usefulness and validity.

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